CERES Terra Edition2A CRS
Data Quality Summary

Investigation:	**CERES**
Data Product:	**Clouds and Radiative Swath (CRS)**
Data Set:	**Terra (Instruments: CERES-FM1 or CERES-FM2, MODIS)**
Data Set Version:	**Edition2A**

The purpose of this document is to inform users of the accuracy of this data product as determined by the CERES (Wielicki et al., 1996) Science Team. This document briefly summarizes key validation results, provides cautions where users might easily misinterpret the data, provides links to further information about the data product, algorithms, and accuracy, and gives information about planned data improvements. This document also automates registration in order to keep users informed of new validation results, cautions, or improved data sets as they become available.

This document is a high-level summary and represents the minimum necessary information for scientific users of this data product.

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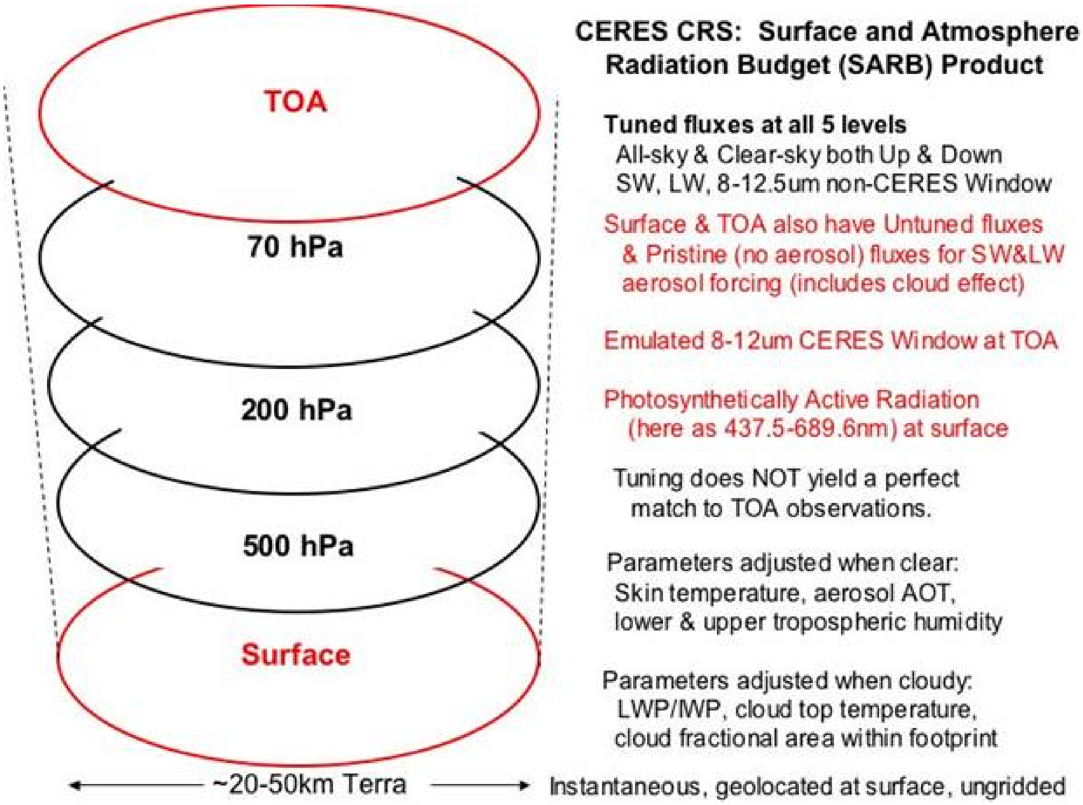


Figure 1 CRS: CERES Surface and Atmosphere Radiation Budget (SARB) product

Nature of the CRS Product

Introduction

The CRS (Cloud Radiative Swath) product (Figure 1) is designed for studies of the energy balance within the atmosphere, as well as climate studies which require fields of clouds, humidity and aerosol that are consistent with radiative fluxes from the surface to the Top Of the Atmosphere (TOA). CRS software is developed and managed by the CERES Surface and Atmospheric Radiation Budget (SARB) Working Group (WG). Like its parent Single Scanner Footprint (SSF), CRS corresponds to an instantaneous CERES broadband footprint. The footprint has nominal nadir resolution of 20 km for half power points but is larger at other view angles (Figure 2). The major inputs (Figure 3) to the CRS software are the instantaneous scene identification, cloud and aerosol properties from the MODIS cloud imager pixels (resolution ~1 km), and TOA radiation (from the CERES instrument) contained on the respective SSF footprint; along with 6-hourly gridded fields of temperature, humidity, wind, and ozone, and climatological aerosol data contained on the Meteorological, Ozone, and Aerosol (MOA) product. MOA includes meteorological data provided by GEOS4 and the Stratospheric Monitoring Group Ozone Blended Analysis (SMOBA, Yang et al., 2000) ozone profiles from NCEP. Aerosol information is taken from MODIS and from the NCAR Model for Atmospheric Transport and Chemistry (MATCH, an assimilation that here also employs MODIS, Fillmore et al. 2004, Collins et al. 2001). The CRS product contains the SSF input data; through-the-atmosphere radiative flux profiles calculated by SARB algorithms that partially constrain to CERES TOA observations; adjustments to key input parameters (i.e., optical depth for cloudy footprints and skin temperature for clear footprints); and diagnostic parameters. CRS fluxes are produced for shortwave (SW), longwave (LW), the 8.0-12.0 µm window (WN), both upwelling and downwelling at TOA, 70 hPa, 200 hPa, 500 hPa, and the surface (Figure 3). To permit the user to infer cloud forcing and direct aerosol forcing, we include surface and TOA fluxes that have been computed for cloud-free (clear) and aerosol-free (pristine) footprints; this accounts for aerosol effects (SW and LW) to both clear and cloudy skies. Charlock et al. (2004) has much of the narrative in the present document and describes a field test of the SW radiative transfer code. The user can refer to the application of the earlier TRMM SARB product in the following: Charlock et al. (2002) compare time series of computed fluxes at TOA with CERES observations and illustrate how the flux profiles are related to the tropical circulation. Rutan et al. (2002) point out that the TRMM results do not support "anomalous absorption" of SW by clouds. Rose and Charlock (2002) describe some changes in the radiative transfer code which are used in this Terra product (but not in TRMM).

How well do the SARB fluxes described here compare with observations? Table 1 provides a very rough answer by comparing with ground observations of downwelling LW and SW, and collocated CERES TOA observations of upwelling LW (OLR) and reflected SW, as biases (computed minus observed) for about 50 ARM, SURFRAD, CMDL, and BSRN sites. While computed SARB fluxes have been here tuned with CERES observations at TOA, *absolutely no ground radiometric data are used for input or tuning*. In the first row of Table 1, the mean observed downwelling LW to the surface is 292.2 Wm^{-2} for the 15918 samples of matched SARB retrievals at the ~50 sites; the bias (tuned minus observed) was -3.9 Wm^{-2}; the RMS error was 22.7 Wm^{-2}; the aerosol forcing (computed flux with aerosols minus computed flux with no aerosols) was 1.1 Wm^{-2}. In the second row, there were fewer (7862) samples of matched SARB SW insolation and ground observations than for LW down, because SW is not computed for the night overpasses. The RMS error (92.9 Wm^{-2}) for SW insolation is large because the surface radiometer measures the insolation at only a single point (idealized as X in Figure 2) of a frequently cloudy sky, while the computation uses satellite data to span the entire footprint. The aerosol forcing to all sky SW insolation is -10.3 Wm^{-2}, almost a factor of four larger than that to SW reflected at TOA (2.5 Wm^{-2}). If the fluxes in Table 1 are not sufficiently accurate for the particular application of the reader, he or she is thereby spared the time needed to survey of the rest of this document. If the fluxes in Table 1 are sufficiently accurate or interesting, note the text accompanying the corresponding full Table 4 (tuned) and Table 5 (untuned) for various sky conditions near end of this document. Tables 4 and 5 are also on the web (seek "CERES CAVE" and then "Validation Plots and Statistics"), as are a point and click version of the Langley Fu-Liou code which computed the fluxes, easy-to-use subsets of SARB at the 50 sites, and the independent ground-based radiometric record used for validation. These tables represent neither the global mean nor the diurnal mean; they cover only the coincidences up of a specially selected set of ground sites with CERES SARB at times of Terra overpass. If expressed as a diurnal mean (24 hour), the bias for all-sky SW insolation of 9.1 Wm^{-2} in Table 1 would be reduced to ~3 Wm^{-2}.

Table 1: Abbreviated comparison of computed fluxes (CERES Terra CRS Edition 2A) with collocated TOA and ground observations at roughly 50 "CAVE" sites for all-sky conditions at times of Terra overpass during 2001.

		Observed Wm^{-2}	Samples N	Bias Wm^{-2}	RMS Wm^{-2}	Aerosol Forcing Wm^{-2}
Surface	LW down	292.2	15918	-3.9	22.7	1.1
	SW down	482.3	7862	9.1	92.9	-10.3
TOA	LW up	222.1	16297	0.8	5.0	-0.4
	SW up	263.1	7844	1.4	12.3	2.5

A full definition of each parameter will be contained in the CRS Collection Guide, which has not been written yet. The present lengthy document should make the definitions clear to a reader having the CRS Data Product Catalog in hand. Informal extensions to the CRS Data Quality Summary will be posted under "CRS Advice" at the CAVE web site.

The SSF parent of this data set is CER_SSF_Terra-FM1-MODIS_Edition2A and CER_SSF_Terra-FM2-MODIS_Edition2A. The first few hundred parameters on a CRS file are duplicates of SSF. (See SSF Data Products Catalog (PDF).) Before using these parameters, please consult the SSF Quality Summary. Definitions of these parameters are available in the SSF Collection Guide.

When referring to a CERES data set, please include the satellite name and/or the CERES instrument name, the data set version, and the data product. Multiple files which are identical in all aspects of the filename except for the 6 digit configuration code (see Collection Guide - when available) differ little, if any, scientifically. Users may, therefore, analyze data from the same satellite/instrument (here Terra/CERES/MODIS), data set version (here Edition2A), and data product (here CRS) without regard to configuration code. This CRS data set may be referred to as "CERES Terra Edition2A CRS".

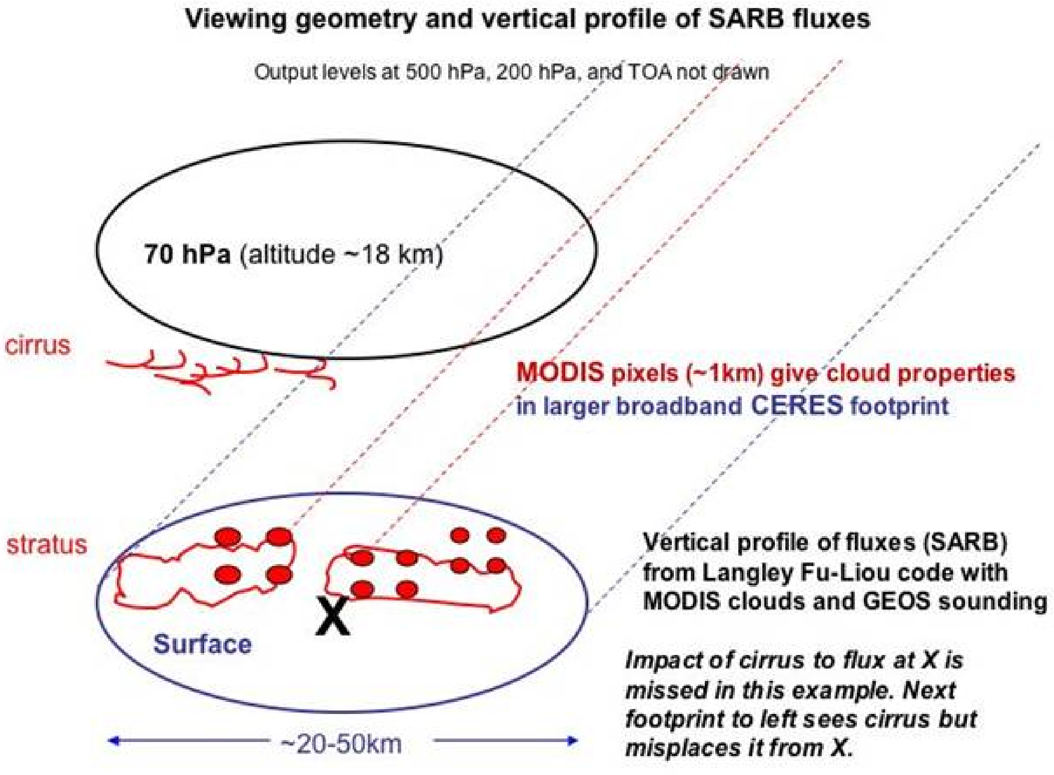


Figure 2: Typical viewing geometry showing small MODIS pixels within large CERES footprints

Constrainment (tuning)

In short, the SARB flux profile in the CRS product is the output of a highly modified Fu and Liou (1993) radiative transfer code. The code is run at least twice for each broadband CERES footprint, in order to adjust inputs that determine the vertical profile of radiative fluxes. The constrainment (or tuning) algorithm does NOT yield a perfect match to CERES broadband observations at TOA. Constrainment (Rose et al. 1997; Charlock et al. 1997) is an approach to minimize the normalized, least squares differences between (1) computed TOA parameters and adjusted values for key inputs and (2) observed TOA parameters and initial values for key inputs. The algorithm assigns an a priori numerical "sigma" (uncertainty) to each TOA parameter and key input parameter. The "sigmas" for TOA parameters (first group in Table 2) are the anticipated RMS differences between observations based on the core CERES instrument and the outputs of radiative transfer calculations. The sigmas for key input parameters (the second and third groups labeled "cloud" and "other" in Table 2) are the anticipated RMS differences between the initial (untuned) and final values of those key input parameters (tuned).

The inputs for radiative transfer calculations are depicted in Figure 3. The initial values of cloud parameters are taken from the SSF; they are narrowband imager-based retrievals of cloud properties. Initial values of other key input parameters such as precipitable water (PW) and upper tropospheric humidity (UTH) are based on GEOS4. Aerosol information is taken from MODIS when available for the instantaneous CERES footprints. If the MODIS instantaneous aerosol optical thickness (AOT) is not available for the footprint, we interpolate AOT from a file of the MODIS Daily Gridded Aerosol for the calendar month of processing. When cloudiness in the footprint exceeds 50%, or when there is no MODIS AOT, we use AOT from the NCAR Model for Atmospheric Transport and Chemistry (MATCH).

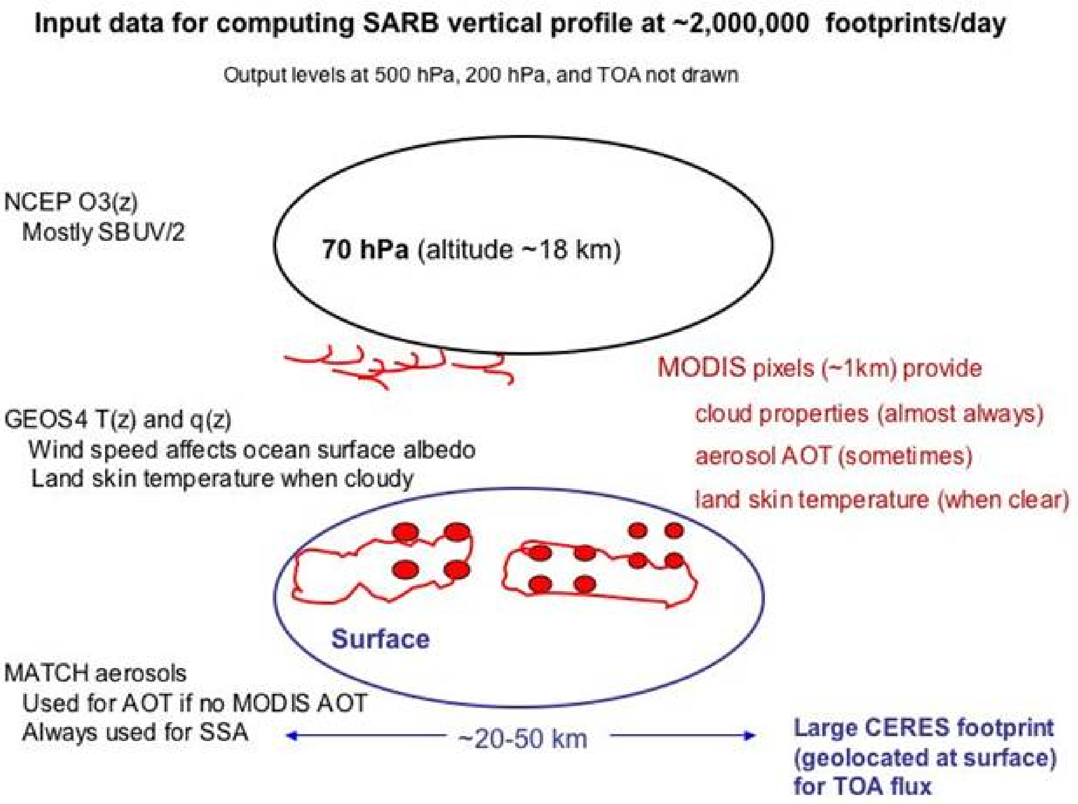


Figure 3. Inputs for determining the Surface and Atmosphere Radiation Budget (SARB)

If the reported fraction of cloudiness on the SSF file exceeds 0.05, the values of the third group of "other" (Table 2) parameters are frozen. The cloud optical depth, cloud fractional area, and cloud top height (second group in Table 2) are adjusted instead. Cloud optical depth is modified by adjusting liquid water path (LWP) or ice water path (IWP), rather than droplet or crystal size. When the SSF input (which includes microwave-based maps of snow cover and sea ice) indicates snow or ice beneath the clouds, the very first step in daytime constrainment is a simultaneous adjustment of the initial cloud optical depth and surface albedo to match the broadband TOA albedo observed by CERES; then constraiment proceeds as stated in the previous two sentences.

If the reported fraction of cloudiness on the SSF file is less than 0.05, the cloud parameters (second group in Table 2) are frozen, and the constrainment algorithm adjusts parameters from the third ("other") group in Table 2. For such clear and almost clear footprints over the ocean (note "ocean" column at the bottom of Table 2), the constrainment adjusts the surface skin temperature, lower tropospheric humidity (LTH), upper tropospheric humidity (UTH), and AOT. For such clear and almost clear footprints over land, the surface albedo is also adjusted; and the sigma (a priori uncertainty) for skin temperature is increased, causing a larger adjustment in skin temperature over land than over ocean. The SARB algorithm does not adjust temperature above the surface.

Every CRS footprint has TOA parameters (first box in Table 2) with observed values taken from SSF, untuned values from the initial run of the Fu-Liou code, and tuned values from the constrainment process. Every CRS footprint has input values for cloudy parameters (second box in Table 2) which are taken from SSF and "other" parameters (third box in Table 2); and it has slots for the adjustments to each of these parameters by the constrainment process. This is summarized in Figure 1. For a discussion of observed TOA parameters (first box in Table 2) or unadjusted cloudy or clear parameters (second and third boxes in Table 3), note the SSF Quality Summary.

What is the implication of an assigned sigma of 1.0% for broadband LW flux versus 2.0% for window WN flux versus 5.0% for filtered window radiance (top group in Table 2)? Among those 3 parameters, broadband LW flux (OLR) has the smallest sigma. Thus OLR is the tightest constraint among those 3 parameters. Adjustable parameters like cloud optical depth and surface skin temperature are pulled more toward new values causing a better match between computed and observed OLR (sigma 1%), than they are pulled to new values causing a better match between computed and observed filtered window radiance (sigma 5%). The large sigmas of 5% for the broadband LW and filtered window radiances in Table 2 in fact produce hardly any adjustments in direct response to the radiances. The smallest sigmas (1%) are assigned to broadband reflected SW and to broadband LW fluxes, as they are the primary earth radiation budget (ERB) observables. If we had less confidence in the inversion from radiance ($Wm^{-2}sr^{-1}$) to flux (Wm^{-2}) on the CERES SSF record, the sigmas of broadband LW flux and broadband LW radiance could hypothetically be reversed. There is no sigma for reflected SW radiance because our fast radiative transfer code does not simulate SW radiance.

Table 2: The a priori uncertainty ("sigma") for each adjustable parameter in the constrainment (tuning) algorithm that produces the Surface and Atmosphere Radiation Budget (SARB) for CERES footprints

Observed by CERES at TOA (SSF record)			
TOA parameters	**Sigma (%)**	**Minimum sigma (MKS)**	**Parameter**
	1.0 %	2.0 Wm^{-2}	reflected SW flux
	1.0 %	2.0 Wm^{-2}	broadband LW flux
	2.0 %	1.0 Wm^{-2}	window WN flux
	5.0 %	0.3 Wm^{-2} sr^{-1}	broadband LW radiance
	5.0 %	0.3 Wm^{-2} sr^{-1}	filtered window radiance
From MODIS imager (SSF record)			
Cloud parameters	**Sigma**		**Adjustable parameter**
	0.15		d ln(τ) τ = optical depth
	2.0		cloud top temperature
	0.05		total cloud fraction in footprint
	0.025		fraction swap of 2 types in footprint (i.e., increase Cu and decrease Ci)
From various sources			
Other parameters	**Ocean**	**Land**	**Adjustable parameter**
	1.0 K	4.0 K	surface skin temperature
	0.15	0.10	d ln(PW) PW: surface to 500 hPa
	0.15	0.10	d ln(UTH) upper tropos. humidity
	0.002	0.015	surface albedo
	0.50	0.10	d ln(AOT)

Definitions of SW, LW, and Window

CERES geophysical products define SW (shortwave or solar) and LW (longwave or thermal infrared) in terms of physical origin, rather than wavelength. We refer to the solar energy which enters and exits (overwhelmingly by reflection) the earth-atmosphere system as SW. LW is regarded as the thermal energy which is emitted by the earth-atmosphere system. There is no wavelength of demarcation, for which all radiation at shorter (longer) wavelengths is called SW (LW). Thus defined, roughly 1% of the incoming SW is at wavelengths longer than 4 µm. A small amount of radiation from the sun enters the troposphere at 10 µm. This too is regarded as SW, and we strive to account for it in successive SW products. Less than 1 Wm^{-2} of OLR is at wavelengths below 4 µm. If the radiation was originally emitted by a thermal process in the earth-atmosphere system, we regard it as LW, even if it is subsequently scattered. When a small amount of thermal radiation is emitted from the surface of the Sahara at 6 µm, and a portion of that is scattered upward to space through a cirrus cloud, said portion is regarded as LW. The 8.0-12.0 µm window (WN) products are a repository of the thermal radiation in the window. We strive to eliminate any signal of solar contamination in an 8.0-12.0 µm window or broadband LW product.

The official CERES window (WN) spans 8.0 µm to 12.0 µm (1250 cm^{-1} to 833.333 cm^{-1}). The TOA observed SSF window products use this interval, as do the TOA emulated window product. CRS users should be aware that the vertical profiles of window flux use a DIFFERENT spectral interval, 8.0 µm to 12.5 µm (1250 cm^{-1} to 800 cm^{-1}), as explained in the next section.

Radiative Transfer Code

CRS uses a fast, plane parallel correlated-k radiative transfer code (Fu and Liou, 1993, Fu et al., 1998, 1999) which has been highly modified. It is referred to as the "Langley Fu-Liou code". An economical 2 stream calculation is used for SW. The LW calculation employs a 2/4 stream version, wherein the source function is evaluated with the quick 2-stream approach, while radiances are effectively computed at 4 streams. Constituents for the thermal infrared include H_2O, CO_2, O_3, CH_4 and N_2O. A special treatment of the CERES 8.0-12.0 µm window includes CFCs (Kratz and Rose, 1998) and uses the Clough CKD 2.4 version of the H_2O continuum (the original Fu-Liou employed the Roberts continuum). In collaboration with Dr. Qiang Fu, the Fu-Liou code was modified to include 10 separate bands between 0.2-0.7 µm to better account for the interaction of Rayleigh scattering, aerosols, and absorption by O_3 and a minor band of H_2O. In cooperation with Dr. Seiji Kato,, we have included the HITRAN2000 data base for the determination of correlated k's in the SW (Kato et al., 1999). We make a first order accounting for the inhomogeneity of cloud optical thickness (using the gamma weighted two stream approximation of Kato et al., 2004) in the SW, fitting the 13-element SSF histogram of cloud optical thickness with a gamma distribution. The original code included SW from 0.2 to 4 µm. In addition, we cover the SW at wavelengths larger than 4 µm by simply stuffing the solar insolation beyond 4 µm into a near IR band with strong absorption by H_2O. Downwelling solar photons larger than 4 µm are then mostly absorbed by the model before reaching the middle troposphere. Scattering by cloud particles, aerosols, and a non-black surface is parameterized in LW, as well as SW. For example, the desert surface has reduced thermal emission as it is non-black. As its emissivity is less than unity, the reduction in upward LW emitted by the surface is partly compensated by reflection of the downwelling LW to the surface. The code has been extended with a new band to cover thermal emission from 2200-2850 cm^{-1}.

The Fu-Liou code covers the window with 3 bands from 8.0 µm to 12.5 µm (1250 cm^{-1} to 800 cm^{-1}); vertical profiles of window flux use this interval. A different window interval, 8.0 µm to 12.0 µm (1250 cm^{-1} to 833.333 cm^{-1}), is used for TOA observations on SSF and for the formal TOA emulations. The 8.0 µm to 12.0 µm TOA window parameters on SSF are emulated (modeled) as follows with the Langley Fu-Liou code. First, the code produces window radiance and flux for 8.0 µm to 12.5 µm at TOA; the modeled radiance and flux constitute a theoretical Angular Distribution Model (ADM relating radiance to flux) for the footprint. Second, a straightforward parameterization based on MODTRAN4 (Anderson et al.) is then applied; the inputs are view zenith angle and radiance. The parameterization maps the 8.0 µm to 12.5 µm Fu-Liou radiance to an "unfiltered" (geophysical) 8.0 µm to 12.0 µm emulated radiance and also to a "filtered" 8.0 µm to 12.0 µm emulated radiance. Recall that the spacecraft itself observes a filtered radiance, a signal which includes the effect of the spectral response of the instrument. It is the task of SSF to account for the spectral response and produce an unfiltered radiance. In the second step here, the spectral response (filter function) of the instrument is modeled, producing an emulated filtered window radiance. Third, the theoretical ADM (based on 8.0 µm to 12.5 µm) converts the unfiltered 8.0 µm to 12.0 µm emulated radiance into an emulated window flux. The unfiltered, emulated window radiance is not archived.

While the original Fu-Liou code offered empirical droplet size spectra based on early field campaign data, we now use theoretical, gamma distributions for the radii of cloud water droplets (Hu and Stamnes, 1994), consistent with the Minnis et al. (1998) retrievals on CERES SSF input stream. The code treats all ice cloud crystals as randomly oriented hexagons characterized by a generalized effective diameter D_{ge}. The SSF cloud retrievals also assume randomly oriented hexagons but express them as effective diameter De. Caution is advised when interpreting CRS results for ice clouds, as both the input cloud retrievals (SSF) and the radiative transfer calculations do not account for the enormous variation of crystal shapes found in nature.

The typical CRS calculation uses 30 atmospheric layers with fixed thickness layers of 10 hPa and 20 hPa nearest the surface. The remainder are placed on a sliding scale following the input value for surface pressure. Additional layers, at levels "custom made" for each footprint, are inserted in the radiative transfer calculation for cloud top and cloud bottom. CRS places the cloud top as per the pressure top retrieved by SSF. The SSF estimate for cloud geometrical thickness is used to specify cloud bottom.

Reflection of SW by Surface

The spectral dependence of surface reflectivity for land surface albedos are specified according to the CERES Surface Properties maps (from CERES/SARB Surface Properties web site) following Rutan and Charlock (1997 and 1999). CRS uses the Wilber et al. (1999) surface LW spectral emissivity maps (which are available at the same URL). Both SW and LW surface maps are keyed to International Geophysical Biospherical Project (IGBP) land types. For the category of Permanent Snow and Ice, the spectral shape of reflectance is taken from a model by Jin et al. (1994) assuming 1000 µm snow grains; a grains size of 50 µm is assumed for the spectral shape of fresh snow. The spectral shape of sea ice also employs Jin et al. (1994).

Ocean spectral albedo is obtained using a look up table (LUT) based on discrete ordinate calculations with a sophisticated coupled ocean atmosphere radiative transfer code (COART, Jin et al., 2002, 2004; Jin and Stamnes, 1994). Inputs to the look-up table for ocean spectral albedo include cosine of the solar zenith angle (cosSZA), wind speed (from ECMWF), chlorophyll concentration (which has a minor effect on broadband flux), and SW optical depth of clouds and aerosols (from SSF) for the respective spectral interval. The LUT are available online (seek "CERES + CAVE") and easily fit other spectral intervals, such as those of GCM. We also use an empirical correction for surface foam based on wind speed. COART also runs online.

For clear footprints during daytime, the broadband surface albedo is explicitly retrieved using TOA observations and iterations of the Langley Fu-Liou code with the constrainment algorithm; the broadband albedo is then simply a ratio of upwelling to downwelling SW at the surface. When a CRS footprint contains clouds, the broadband surface albedo is assumed using the Surface Albedo History (SAH) procedure. The SAH algorithm is run at the start of each month of CRS processing. SAH identifies the clear SSF footprints during the month with the most favorable geometry for the retrieval of surface albedo: those with large values of cosSZA. SAH uses a quick table look-up to the Langley Fu-Liou code that relates TOA albedo, surface albedo, cosSZA, precipitable water (PW), and aerosol optical thickness (AOT). Using the footprint AOT (from MODIS or the MATCH aerosol assimilation), the look-up retrieves a first guess surface albedo for the month. This first guess surface albedo corresponds to a clear SSF/CRS footprint. The monthly value for the first guess surface albedo is then written to a SAH file for each of the 10 by 10 minute gridded tiles, whose center points are contained in the clear footprint. Each 10 by 10 minute gridded tile of land is thus given an initial broadband surface albedo for the month. The SAH albedo is stored internally as a reference value A_o using the Dickinson (1982) relationship

$$A(\cos SZA) = A_o(1 + d)/(1 + 2d \cos SZA)$$

where d is specified for each IGBP type and A_o is the albedo at cosSZA of 0.5. The look-up, first guess values of A_o for the various 10 by 10 minute tiles are then available to construct a fixed broadband surface albedo as an input for radiative transfer calculations with any cloudy footprint, for which we assume A(cosSZA=0.5). When a land footprint is clear during daylight, the surface albedo is explicitly retrieved with the CRS constrainment algorithm by iterating the code (not as a quick table look up) with GEOS4 sounding and MODIS (MOD04) and/or MATCH aerosol inputs. The quality of the surface albedo retrieval depends heavily on the realism of simulation of AOT and the CRS assignment of the corresponding single scattering albedo (see aerosol discussion and Table 3). The most reliable CRS values of surface albedo are expected for clear footprints under high sun, in regions and seasons with low AOT. Unfortunately, the CRS surface albedo retrieval for desert is not reliable, because we assume too much absorption by desert dust (see next section).

The Photosynthetically Active Radiation (PAR) product, which is generated only at the surface, is simply the SW output from 437.5 to 689.6 nm, rather than the traditional PAR interval of 400-700 nm. To date, we have not compared this non-traditional PAR with any surface observations.

Treatment of Aerosols

Each footprint accounts for the effect of aerosols on SW fluxes, LW fluxes and 8.0-12.0 µm window fluxes at all levels, and on broadband LW and filtered window radiance at TOA. Aerosol information is taken from MODIS (the MODIS Atmospheres MOD04 product described by Kaufman et al., 1997) when available for the instantaneous CERES footprints. Over the ocean, MOD04 is used for 7 wavelengths; the AOT is interpolated to the remainder of the spectrum using the selected aerosol type, as specified below. Over the land, MOD04 provides AOT at 3 wavelengths, and the MOD04 Angstrom exponent is used to guide the extension over the spectrum. If the MOD04 instantaneous AOT is not available for the footprint, we temporally interpolate from a file of the MODIS Daily Gridded Aerosol as noted earlier. When cloudiness in the footprint exceeds 50%, or when there is no MODIS AOT, we use AOT from the NCAR Model for Atmospheric Transport and Chemistry (MATCH, an assimilation that here also employs MODIS, see Fillmore et al., 2004 and Collins et al., 2001). MOD04 does not span the entire globe; it does not include the cryosphere and most deserts, for example. When AOT is taken from MATCH, we assume it for one wavelength only, 0.63µm (a coding error assumed another value, but the impact is generally< 1%). MATCH provides AOT according to 7 types (Table 3) on a daily basis over the globe for all sky conditions. Sources of aerosol in MATCH include formation from industrial emissions (as a climatology). More timely MATCH AOT inputs include MOD04-based retrievals over clear regions; and an algorithm for wind-blown dust. MATCH itself accepts the NCEP analysis as an meteorological input. MATCH advects aerosols and removes aerosols with wet (cloudy) and dry processes. For economy in transferring MATCH files from NCAR, we take on the column AOTs of each type (rather than the profile) and assume "climatological" vertical scale heights that do not vary in space and time (Table 3).

While AOT is based on either MOD04 (a satellite retrieval) or MATCH (a model), aerosol type is always taken from MATCH. Aerosol type here guides the selection of the asymmetry factory (g) and the single scattering albedo (SSA). The spectral single scattering albedos and asymmetry factors are assumed from the Tegen and Lacis (1996) and OPAC-GADS (Hess et al., 1998; d'Almeida et al., 1991) models. Footprints with significant amounts of Tegen and Lacis 2.0 µm dust and/or OPAC soot will have strong absorption by aerosols in the computed SW. As CRS has coarse vertical resolution (i.e., outputs at surface and 500 hPa), the assignment of scale height should have a small effect on SW in most clear footprints. But if a dust outbreak spreads to say 6 km, the CRS aerosol forcing in the LW will not be realistic at either the surface or at TOA.

Recent studies with AERONET (Dubovik et al., 2002) suggest that absorption is too high in the Tegen and Lacis 2.0 µm dust. If Dubovik et al. are correct, both our computed atmospheric absorption for desert dust and our retrieved desert surface albedos would then be high, too. But dust optical depths in the MATCH assimilation are overwhelmingly of the 0.01-1.0 µm class (Table 3), for which we assign the radius 0.5 µm. Single scattering albedos for the Tegen and Lacis 0.5µm dust are closer to the values reported by Dubovik et al. Any CRS footprint containing a significant loading of desert dust will have values for computed SW fluxes that are suspect. As the surface albedo is the ratio of two computed SW fluxes, the surface albedo over deserts (i.e., the Sahara, which has much dust) is also suspect.

The user is advised that fluxes based on satellite retrievals of aerosols are not expected to have the relative veracity of say, fluxes based on satellite retrievals of SST. Further caution is advised when an aerosol assimilation (MATCH) is applied.

Table 3: Assignment of aerosol characteristics

MATCH aerosol type	CRS aerosol optics	scale height
dust (0.01-1.0 µm)	1. dust (0.5 µm) Tegen-Lacis	3.0 km
dust (1-10 µm)	2. dust (2.0 µm) Tegen-Lacis	1.0 km
dust (10-20 µm)	2. dust (2.0 µm) Tegen-Lacis	1.0 km
dust (20-50 µm)	2. dust (2.0 µm) Tegen-Lacis	1.0 km
hydrophilic black carbon	3. soot (OPAC)	3.5 km
hydrophobic black carbon	3. soot (OPAC)	3.5 km
hydrophilic organic carbon	4. soluble organic (OPAC)	3.8 km
hydrophobic organic carbon	5. insoluble organic (OPAC)	3.8 km
Sulfate	6. sulfate (OPAC)	3.5 km
sea salt	7. sea salt (OPAC)	0.5 km

Comparison of computed radiation with observations at TOA

Terra CRS is based on a routine subset of every other SSF footprint. CERES observations of radiances ($Wm^{-2}sr^{-1}$) at satellite altitude are reported on the SSF file, a key source for the computed radiation fields reported here as CRS. Observed broadband SW, broadband LW (OLR), and window (8-12 µm) fluxes (irradiances in Wm^{-2}) at the top of the atmosphere (TOA) reference level are interpreted on SSF from (1) observed radiances at the respective footprints and (2) and sets of statistics at many footprints with similar characteristics (i.e., scene type and SZA). Figure 4 contains "raw" statistics of footprints from the entire globe for one day; they have not been gridded to correctly represent particular regions of the globe. Terra CRS is based on a routine subset of every other (50%) of SSF footprints. The scan pattern of CERES causes these "raw" statistics to be over-weighted at higher latitudes; the poles are more frequently visited than a given point at the equator. In Figure 4 we compare both untuned (on the left) computed fluxes (CRS) and tuned (constrained, on the right) with observations (SSF). The performance of the SW (see untuned in top left) is typical: a bias of 5.66 Wm^{-2} (the calculations reflect too much) and an RMS of 24.64 Wm^{-2}. This SW bias, an error of about 2%, is quite good; it attests to the high quality of the cloud retrievals used to compute CRS. The bias for untuned OLR (lower left) is unusually good at only 0.11 Wm^{-2} for this date; the RMS error for OLR is 8.27 Wm^{-2} (a typical value for most dates). Application of the constrainment, which is designed to reduce the RMS error, produces better agreement for tuned fluxes on the right.

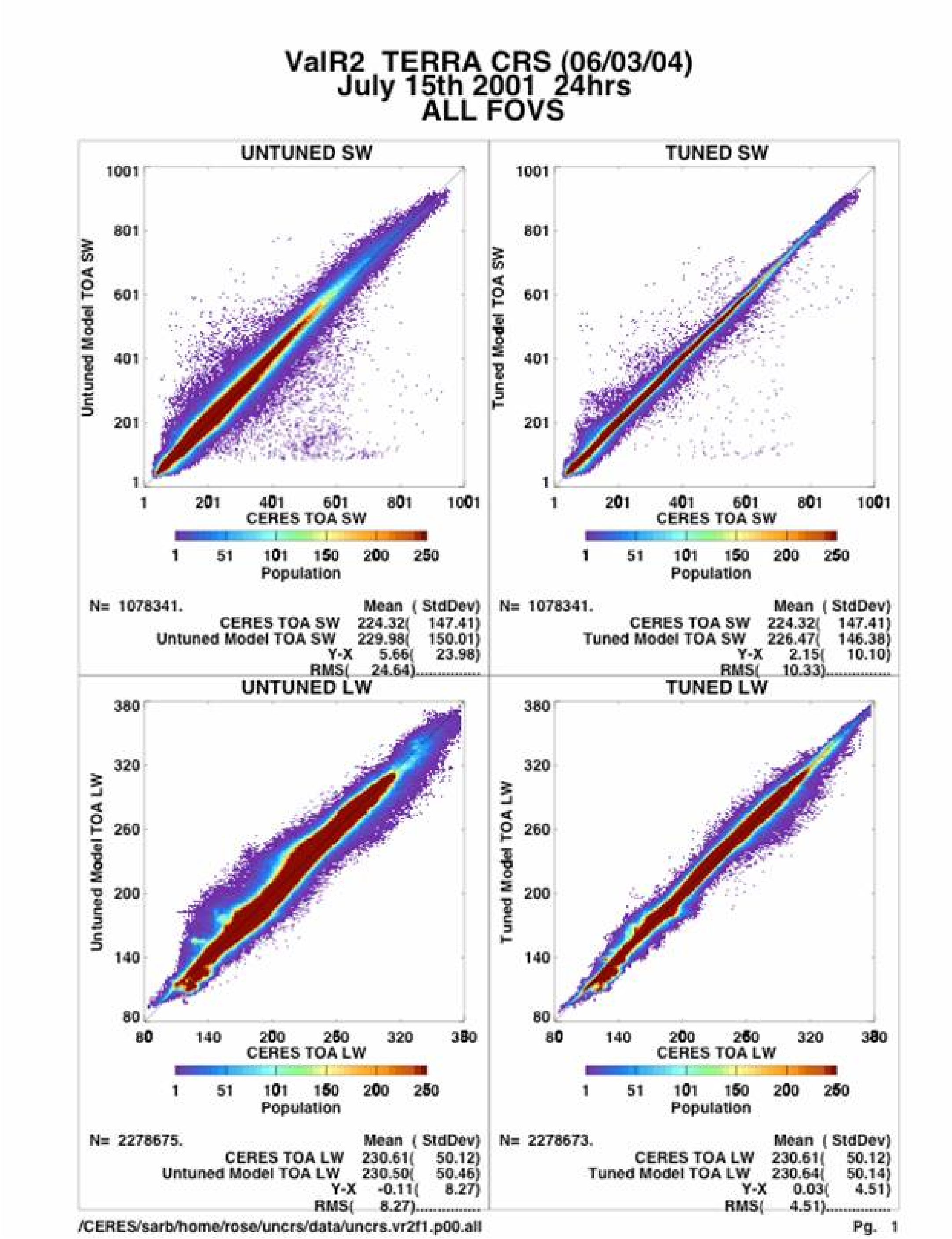


Figure 4. Comparison of computed fluxes (CRS), both untuned and tuned, with observations (SSF) at TOA for 15 July 2001."ValR2" denotes the application of software identical to that used to produce Edition 2A.

While Figure 4 informs on SW and LW broadband fluxes for a single day over both land and sea, Figures 5 and 6 show only SW fluxes but for several months and just over the oceans. We focus on the ocean, because over land our surface albedos are adjusted to give better agreement with the CERES TOA observations under clear conditions. Over the ocean, spectral surface albedo is selected a priori from a well-validated look-up-table (sea ice, for which we adjust the ocean surface albedo significantly, is the exception). Hence the calculation of reflected SW at TOA over the ocean is a more exacting test of the radiative transfer code and the cloud and aerosol properties used for inputs. The values of reflected SW at TOA in Figure 5 are raw means of *day and night* and are typically 120 Wm^{-2}, only half those of the daytime-only SW at TOA in Figure 4. Recall that Figure 4 (all-sky daytime, land plus ocean) indicated an untuned SW bias of 5.66 Wm^{-2}. Figure 5 (all-sky day plus night, ocean only) shows a untuned bias of roughly 5 Wm^{-2}: we compute a relatively larger excess of reflected SW over water. The excess is due to clouds. Figure 6 shows the much smaller biases for the reflected SW at TOA computed under clear conditions. Typical values for reflected SW at TOA over a cloudless ocean are ~80 Wm^{-2} for much of the day. In contrast, the day *plus* night means in Figure 6 are under ~40 Wm^{-2}, for which the monthly biases are only 1-2 Wm^{-2}. The small bias of 1-2 Wm^{-2}, where computed, untuned reflection at TOA over clear ocean exceeds observations only slightly (Figure 6), suggests that the Langley Fu-Liou code and the inputs for surface albedo and aerosols are here sound. The larger bias of 5 Wm^{-2} for all sky (Figure 5) then suggests possible problems with either the parameterization of cloud properties in the code or in the retrievals of cloud properties used for input; the bias of 5 Wm^{-2} for day plus night translates into bias of 10 Wm^{-2} for daytime only satellite overpass (~1030 local) and roughly 20 Wm^{-2} for daytime with overcast. A survey of aerosol effects, which are treated differently in SARB calculations and in the MODIS cloud retrievals on SSF, indicates that aerosols are not the overall culprit in this ocean-wide discrepancy of modeled versus observed cloud reflection; the same discrepancy occurs in various aerosol regimes. The designations FM1 and FM2 in Figures 5 and 6 are the respective CERES broadband instruments on Terra which produced the record of cross-track TOA flux. SARB Terra fluxes are usually computed from the cross-track CERES record. In cross-track mode, the MODIS narrowband imager and the broadband CERES are essentially simultaneous, and they then have almost the same viewing geometries.

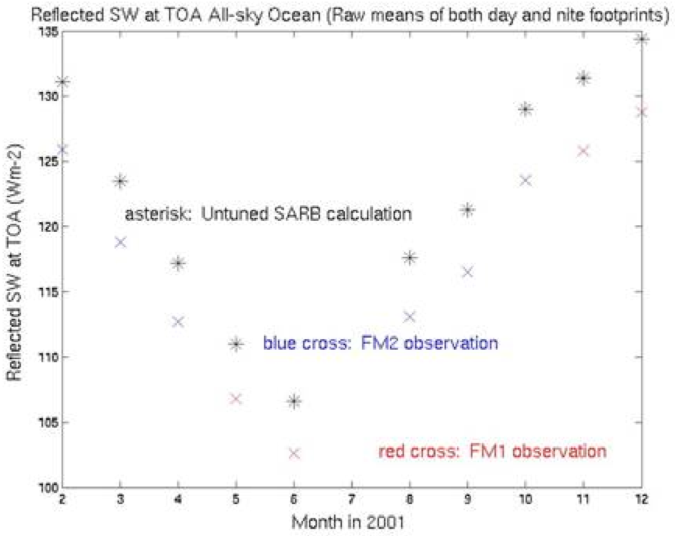


Figure 5. All-sky reflected SW at TOA (Wm^{-2}) over the ocean only. Each value is a raw mean of all footprints processed within a given month during both day and night. Black asterisks denote untuned calculations. Colored crosses denote observations.

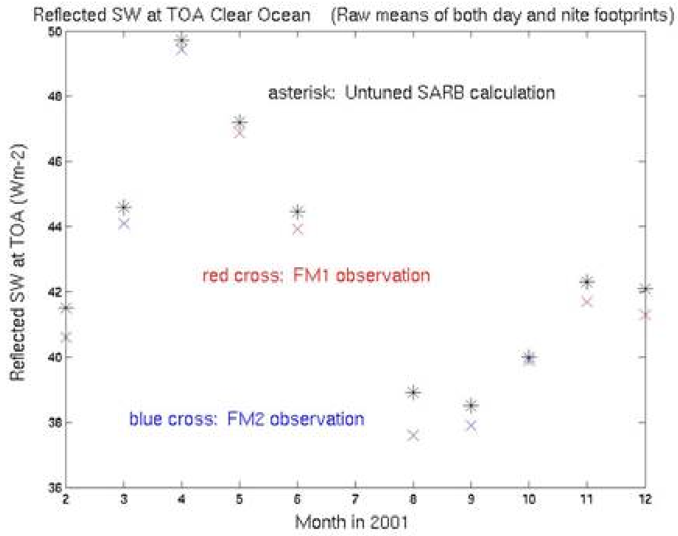


Figure 6. Clear-sky reflected SW at TOA (Wm^{-2}) over the ocean only. Each value is a raw mean of cloud-free footprints processed within a given month during both day and night. Black asterisks denote untuned calculations. Colored crosses denote observations.

Comparison with Surface Observations

Retrievals of surface flux are here compared with surface-based observations which are available online through the CERES "ARM" Validation Experiment (CAVE) web site. CAVE (Rutan et al., 2001) provides high quality surface data at about 50 sites worldwide. About half of the sites are part of the ARM Southern Great Plains (SGP) network (Stokes and Schwartz, 1994). Many CAVE sites, such as the SGP Central Facility, and NOAA SURFRAD (Augustine et al., 2000) and CMDL stations, subscribe to the rigorous BSRN observing protocol (Ohmura et al., 1998). Each CAVE surface observation (CAVE Obs) is expressed as a 30-minute mean. We represent the surface flux over the large span of the satellite footprint by using an adjusted time mean of the point surface observation. While surface SW fluxes in the CRS record are "instantaneous" at their respective SZAs, we have adjusted observed SW fluxes in Table 4 with the formula

Obs SW flux in Table 4 = (CAVE Obs SW flux)*[cos(SZAceres)]/[30 min. mean cos(SZA)]

This converts the 30 minute mean observation to a value that represents the surface flux for the satellite observation. Each sample in Table 4 matches the closest CERES footprint containing a SARB retrieval (one half of the CERES footprints) with the ground measurement during a 30-minute interval; the center of the footprint must be within 15 km of the ground site. Measured values of surface radiation are NOT used for input or constrainment (tuning). Hence the comparison of fluxes at the surface in Table 4 below is a "cold" test. Observed values of TOA radiation are indeed used in constrainment (tuning), as explained earlier. Table 4 covers the CAVE sites for the CERES cross track record during 2001. The six matrices represent all-sky (total-sky) conditions, conditions identified as clear using MODIS, conditions identified as clear using both MODIS and the surface-radiometer-based L/AA (Long and Ackerman, 2000) time series method, overcast conditions as per MODIS, and overcast as per both MODIS and the surface radiometers. Each matrix gives six fluxes; LW down at the surface (LW Dn Sfc), LW up at the surface (LW Up Sfc), SW down at the surface (SW Dn Sfc), SW up at the surface (SW Up Sfc), LW up at TOA (the OLR), and SW up at TOA. Columns give the observed mean, number of samples (N), the bias (computed minus observed), standard deviation of bias, RMS of bias, modeled cloud forcing (computed total sky flux minus computed clear sky), and the aerosol forcing (fluxes computed with aerosols minus fluxes computed without aerosols). Table 1 was an abbreviation of Table 4.

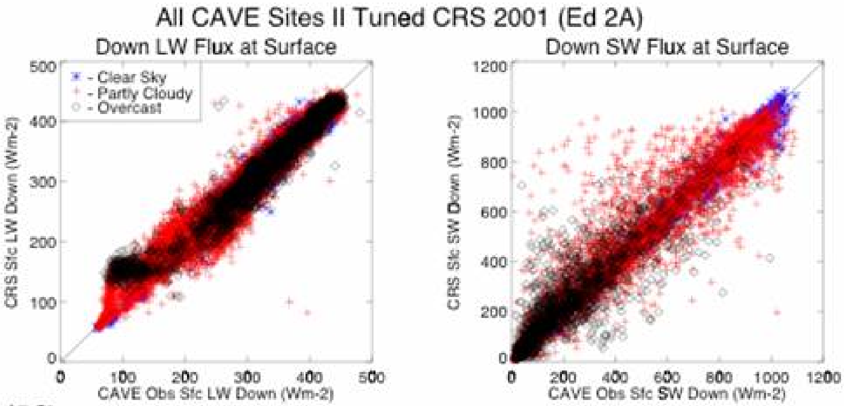
The third row of the first matrix in Table 4 gives an observed insolation (SW Dn Sfc) of 482.3 Wm^{-2} for a 7862 samples (N) and has a bias only 9.1 Wm^{-2}. The mean retrieved insolation has an error of approximately 2%. Because the insolation can have a large spatial variation over a the 20-50km CERES footprint, the RMS error is much larger at 92.9 Wm^{-2}. Biases for the other all-sky fluxes are small, except for the reflected SW at the surface. Here the error is large (-18.8 Wm^{-2}), simply because the ground measurement of the albedo (typically beneath a tower of height 10m) is unlikely to represent that of the CERES footprint. In particular, note the second matrix for clear footprints, whose final column gives the aerosol forcing as the difference of the computed clear sky flux (with aerosols) and the computed pristine flux (no aerosols). This estimate of aerosol clear-sky forcing (dubbed "AOT Frc Clr-Prs" or aerosol optical thickness forcing as clear flux minus pristine flux) to surface insolation (-15.4 Wm^{-2}) should be compared with the smaller bias for computed clear insolation (-5.7 Wm^{-2}) in the same row; this suggests that the aerosol forcing has some credibility for many sites. Also note the reduced aerosol forcing to all-sky insolation (-10.3 Wm^{-2}) in the row above.

A few problems are obvious. One is the fairly disappointing bias of -8.4 Wm^{-2} for downward LW at the surface under clear conditions. The corresponding error for clear-sky OLR is less than 1 Wm^{-2}, both for tuned (Table 5). Over land, clear-sky SARB calculations use surface skin temperature from SSF based on MODIS and a geographically dependent surface emissivity. Investigation of observed surface air temperature at the CAVE sites suggests that much of the bias for downwelling LW at the surface is due to a bias in our input for surface air temperature (GEOS4). Over cloudy land, the GEOS4 surface skin temperature is used for SARB calculations; the small bias for upwelling LW at the surface for overcast (LW Up Sfc is only 1.7 Wm^{-2} for Overcast MODIS in untuned Table 5) shows good consistency of GEOS4 with uplooking surface pygeometer data. The observed surface air temperatures (and a host of other variables) are available as downloadable files (and on demand plots) for most CAVE sites, 48 times per day, since 1998 (seek "CERES + CAVE"). The small bias of -3.9 Wm^{-2} for downward LW at the surface in all-sky conditions suggests that the retrieved cloud areas and cloud base heights from CERES SSF are quite good for the domain mean.

The earlier discussion of Figure 5 pointed out that over the ocean, the values of reflected SW at TOA in the untuned calculations are biased high (as if the model cloud albedos were too large for a given cloud optical depth or the input values for cloud optical depth from MODIS were too large). Table 5 (4) covers untuned (tuned) calculations, but here we are over individual surface sites which are predominantly over the land. In Table 5 the fifth matrix represents overcast skies, and the value 5.1 Wm^{-2} for "Bias CRS-Obs" (bias as calculated minus observed) at "SW Up TOA" shows that over land, too, the untuned calculations are again biased high. The corresponding bias for untuned overcast insolation "SW Dn Sfc" is also positive at 9.4 Wm^{-2}. The sum of 5.1 Wm^{-2} and 9.4 Wm^{-2} suggests a mean excess SW divergence (i.e., lack of absorption compared with observations) of 14.5 Wm^{-2} for the atmospheric column with overcast conditions in daylight (~1030 L Terra overpass). Recall that Table 5 is untuned. What does tuning (Table 4) do with the excess divergence of SW? Tuning chases TOA observations and absolutely ignores ground observations. The corresponding sum of biases in tuned Table 4 for overcast is -1.6 Wm^{-2} (TOA) plus 18.9 Wm^{-2} (surface insolation), yielding 17.3 Wm^{-2}. Tuning has slightly increased the purported tendency to excess SW divergence (from 14.5 to 17.3). This is one problem that tuning does not solve. The comparison with ground data provides insight, however. Using TOA observations only for validation, Figure 5 suggests that our clouds reflect too much. Using both TOA and surface (Tables 4 and 5), we further infer that our clouds reflect too much to TOA AND transmit too much to the surface (the model clouds don't absorb enough). Our special treatment of cloud inhomogeneity has not helped on this front. We have not invoked the biases in "SW Up Sfc" (upwelling SW as measured by short towers) in Tables 4 and 5; the ground measurements are generally obtained over fenced yards whose albedos are not likely to represent conditions over an entire CERES footprint. The cloud absorption discrepancy suggested here is barely a fourth of that advocated by Cess et al. (1996).

Only a few of the CAVE sites have large loading of desert dust. Terra CRS Edition 2A does not fare well, when it is dusty. Saudi Solar Village (SSV) is strongly affected by desert dust. Table 6 gives tuned results for Saudi Solar Village in 2001. (Such tables are available on CAVE for any site and any month.) For clear skies (second matrix in Table 6), the bias for "SW Dn Sfc" is an enormous -52.7 Wm^{-2}. The corresponding clear-sky aerosol forcing "AOT Frc Clr-Prs" to insolation is -36.0 Wm^{-2}, while the aerosol forcing to SW Up TOA is -21.7 Wm^{-2}. Both the surface and TOA aerosol forcings to SW indicate huge absorption by desert dust. MODIS generally does not retrieve AOT over highly reflective surfaces like deserts (i.e., SSV), and we then use MATCH for AOT. An investigation of TOA biases of over ocean regions with significant dust loading (and where MODIS AOT is available) suggests that the problem lies mostly with our assumed value for dust SW single scattering albedo. A forthcoming Edition 2B will use a more advanced treatment of dust optical properties, furnished kindly by Dr. Andrew Lacis at GISS. One bright spot in the current optical properties of dust can be found in Table 6 for the LW: The bias clear sky for "LW Dn Sfc" is only 5.1 Wm^{-2} at SSV, and the large aerosol forcing to LW downwelling at the surface (18.9 Wm^{-2}) suggests that dust has been parameterized reasonably well in the thermal infrared.

Comparisons of computed and observed fluxes at surface and TOA are facilitated with the CAVE web site, which provides both validation data (24 hours a day) and low volume subsets of SARB retrievals (whenever Terra passes a validation site). Much of the comparison to date is favorable. This is a credit to, and a validation of, the inputs from SSF on CERES, the MODIS Atmosphere Team, and the GEOS4 meteorological analysis. Surface radiometric measurements from ARM, SURFRAD, CMDL, and BSRN are obviously a vital component of this test. More detailed study will reveal both the strengths and weaknesses of these valuable resources, and inform us which of their components can be used with confidence in resolving the vexing effects of clouds, aerosols, and surface albedo on global change.



All Sky

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	292.2	15918	-3.9	22.4	22.7	25.6	1.1
LW Up Sfc	353.5	10740	-3.5	23.1	23.4	--------	--------
SW Dn Sfc	482.3	7862	9.1	92.5	92.9	-119.9	-10.3
SW Up Sfc	111.8	5120	-18.8	52.6	55.9	--------	--------
LW Up TOA	222.1	16297	0.8	4.9	5.0	-21.3	-0.4
SW Up TOA	263.1	7844	1.4	12.2	12.3	86.5	2.5

Clear Sky MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	291.5	2743	-8.4	14.5	16.7	--------	2.9
LW Up Sfc	399.0	2223	-1.2	20.2	20.3	--------	--------
SW Dn Sfc	713.6	1396	-5.7	31.1	31.6	32.7	-15.4
SW Up Sfc	149.2	1017	-20.0	29.0	35.1	--------	--------
LW Up TOA	272.6	2822	-0.5	2.6	2.7	--------	-1.2
SW Up TOA	191.6	1430	0.6	3.1	3.1	--------	2.2

Clear Sky MODIS & L/AA

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	276.1	412	-12.4	14.7	19.2	--------	1.0
LW Up Sfc	432.0	380	-5.1	16.6	17.3	--------	--------
SW Dn Sfc	680.2	410	-0.8	19.3	19.3	22.9	-13.1
SW Up Sfc	140.7	379	-20.7	23.7	31.5	--------	--------
LW Up TOA	281.0	419	0.0	2.7	2.7	--------	-0.6
SW Up TOA	164.9	417	0.4	4.4	4.4	--------	3.7

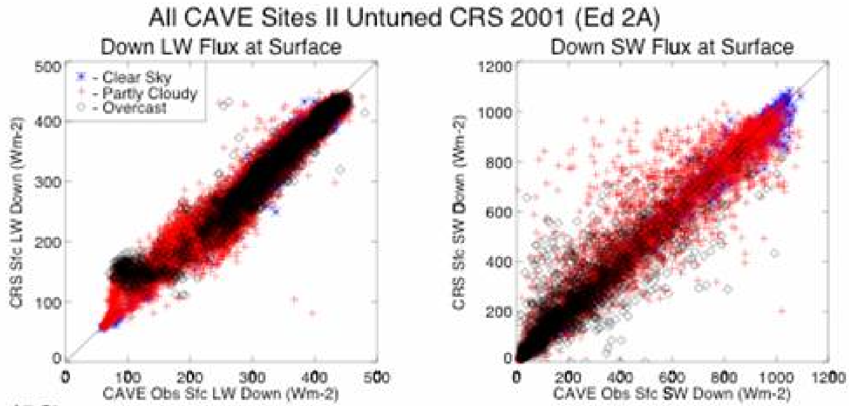
Overcast MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	322.4	3271	-2.7	23.8	24.0	43.5	0.5
LW Up Sfc	338.1	2298	1.7	20.6	20.7	--------	--------
SW Dn Sfc	263.2	1675	18.9	102.0	103.7	-307.2	-5.4
SW Up Sfc	75.2	1209	-15.5	56.6	58.6	--------	--------
LW Up TOA	179.6	3348	0.8	4.3	4.3	-58.9	-0.1
SW Up TOA	412.8	1724	-1.6	16.6	16.7	235.6	0.4

Overcast MODIS & L/AA

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	348.3	791	-5.8	15.5	16.6	52.4	0.3
LW Up Sfc	360.0	602	5.0	19.5	20.1	--------	--------
SW Dn Sfc	186.3	767	43.5	99.0	108.1	-407.4	-4.9
SW Up Sfc	43.5	580	0.2	53.5	53.5	--------	--------
LW Up TOA	186.7	787	1.8	3.6	4.1	-63.0	-0.1
SW Up TOA	488.7	794	-0.4	10.2	10.2	322.2	-0.4

Table 4: Comparison of tuned (constrained) SARB with surface observations (CAVE) and TOA observations (CERES SSF) for the cross-track Terra record in 2001



All Sky

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	292.2	15904	-4.0	22.1	22.5	25.5	1.1
LW Up Sfc	353.9	10749	-3.7	24.2	24.5	---------	---------
SW Dn Sfc	482.6	7853	7.5	90.3	90.6	-121.4	-10.2
SW Up Sfc	111.7	5105	-19.3	52.2	55.6	---------	---------
LW Up TOA	222.2	16277	1.2	8.8	8.9	-20.8	-0.4
SW Up TOA	262.8	7825	3.7	26.9	27.2	86.8	2.4

Clear Sky MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	291.5	2743	-8.4	14.3	16.6	---------	2.9
LW Up Sfc	400.3	2239	-0.9	20.0	20.0	---------	---------
SW Dn Sfc	713.6	1396	-5.6	31.4	31.9	---------	-15.3
SW Up Sfc	148.3	1010	-19.0	29.5	35.1	---------	---------
LW Up TOA	272.6	2822	-0.5	5.1	5.1	---------	-1.1
SW Up TOA	191.6	1430	2.3	6.3	6.7	---------	2.3

Clear Sky MODIS & L/AA

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	276.1	412	-12.6	14.4	19.1	---------	1.0
LW Up Sfc	432.0	380	-4.4	19.0	19.4	---------	---------
SW Dn Sfc	680.2	410	-0.5	19.3	19.3	---------	-13.0
SW Up Sfc	140.7	379	-19.7	23.8	30.9	---------	---------
LW Up TOA	281.0	419	0.4	5.5	5.5	---------	-0.6
SW Up TOA	164.9	417	1.3	5.8	5.9	---------	3.6

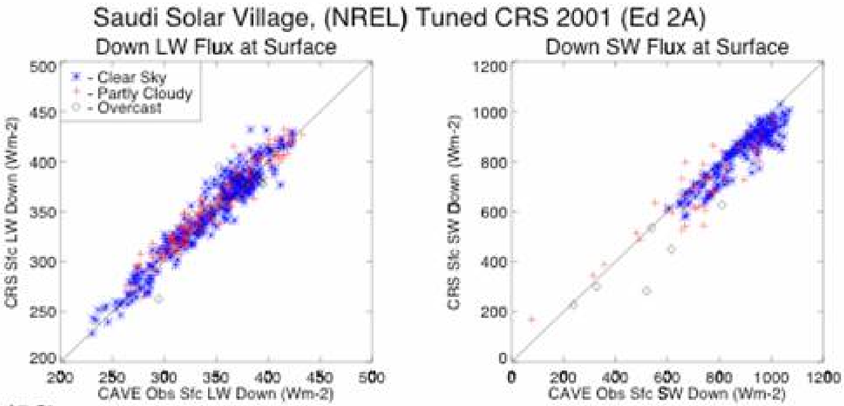
Overcast MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	322.5	3258	-2.8	23.2	23.3	43.1	0.5
LW Up Sfc	338.2	2290	1.7	20.6	20.7	---------	---------
SW Dn Sfc	263.9	1667	9.4	98.3	98.7	-313.4	-4.9
SW Up Sfc	75.4	1204	-17.0	56.5	59.0	---------	---------
LW Up TOA	179.6	3330	0.8	10.4	10.5	-58.5	-0.1
SW Up TOA	412.9	1706	6.1	32.8	33.2	239.4	0.0

Overcast MODIS & L/AA

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	348.2	789	-4.4	14.8	15.4	53.5	0.3
LW Up Sfc	359.9	600	5.0	19.5	20.1	---------	---------
SW Dn Sfc	186.5	767	29.1	97.7	101.9	-418.5	-4.3
SW Up Sfc	43.5	580	-1.1	54.0	54.0	---------	---------
LW Up TOA	186.9	783	4.3	10.1	11.0	-60.0	-0.1
SW Up TOA	488.3	790	8.5	29.0	30.2	328.7	-0.9

Table 5: Comparison of untuned SARB with surface observations (CAVE) and TOA observations (CERES SSF) for the cross-track Terra record in 2001.



All Sky

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	344.3	432	5.9	12.2	13.6	4.3	17.8
LW Up Sfc	462.7	401	14.6	27.5	31.1	--------	--------
SW Dn Sfc	846.8	225	-51.0	54.2	74.3	-52.0	-35.5
SW Up Sfc	228.1	115	8.4	22.4	23.8	--------	--------
LW Up TOA	292.6	432	-0.7	3.8	3.8	-9.3	-5.5
SW Up TOA	324.7	225	0.4	8.7	8.7	18.7	-20.7

Clear Sky MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	342.7	285	5.1	12.2	13.2	--------	18.9
LW Up Sfc	474.3	258	20.6	30.0	36.4	--------	--------
SW Dn Sfc	888.8	171	-52.7	43.5	68.2	169.1	-36.0
SW Up Sfc	245.0	73	8.6	15.3	17.4	--------	--------
LW Up TOA	310.9	285	-0.4	3.2	3.3	--------	-6.8
SW Up TOA	311.6	171	3.2	2.3	4.0	--------	-21.7

Clear Sky MODIS & L/AA

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Dif Bias CRS-Obs	AOT Frc Clr-Prs
LW Dn Sfc	265.3	3	-3.0	10.4	9.1	--------	6.8
LW Up Sfc	415.7	3	17.0	3.2	17.2	--------	--------
SW Dn Sfc	727.4	3	-18.3	5.7	18.9	102.2	-40.8
SW Up Sfc	222.1	3	20.1	17.1	24.5	--------	--------
LW Up TOA	296.0	3	0.8	1.7	1.6	--------	-2.0
SW Up TOA	276.2	3	1.0	0.3	1.0	--------	-5.9

Overcast MODIS

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	362.9	19	3.6	16.7	16.6	30.6	9.5
LW Up Sfc	420.0	18	5.0	23.3	23.1	--------	--------
SW Dn Sfc	508.1	6	-104.3	102.3	140.0	-561.6	-41.2
SW Up Sfc	138.8	6	-4.6	35.2	32.5	--------	--------
LW Up TOA	172.2	19	-1.8	2.8	3.3	-95.6	-0.3
SW Up TOA	525.2	6	-5.0	10.2	10.6	252.8	-9.4

Overcast MODIS & L/AA

	Obs Mean	N	Bias CRS-Obs	Std Dev	RMS	Mod Frc All-Clr	Forcing All-CNA
LW Dn Sfc	--------	--------	--------	--------	--------	--------	--------
LW Up Sfc	--------	--------	--------	--------	--------	--------	--------
SW Dn Sfc	--------	--------	--------	--------	--------	--------	--------
SW Up Sfc	--------	--------	--------	--------	--------	--------	--------
LW Up TOA	--------	--------	--------	--------	--------	--------	--------
SW Up TOA	--------	--------	--------	--------	--------	--------	--------

Table 6: Comparison of tuned SARB with surface observations at Saudi Solar Village (SSV) and TOA observations (CERES SSF) for the cross-track Terra record in 2001.

User Applied Revisions for Current Edition

The purpose of User Applied Revisions is to provide the scientific community early access to algorithm improvements which will be included in the future Editions of the CERES data products. The intent is to provide users simple algorithms along with a description of how and why they should be applied in order to capture the most significant improvements prior to their introduction in the production processing environment. ***It is left to the user to apply a revision to data ordered from the Atmospheric Science Data Center.*** Note: Users should never apply more than one revision. Revisions are independent.

CRS Edition2A-Rev1

The end product of Terra CRS Edition2A, is a "tuned" flux, which has been constrained to more closely approach CERES observations at TOA by modifying inputs like cloud optical depth, surface albedo, etc. Tuned CRS fluxes are hardly ever equal to observed SSF fluxes. Untuned CRS fluxes can be obtained by subtracting the "adjustment" from the "tuned" flux; the tuned fluxes and the adjustments are archived. Over land and over the cryosphere, even the untuned fluxes are affected by the CERES TOA observations of SW, as they are used to estimate surface albedo. Over the ice-free ocean, CERES TOA SW observations do not affect untuned CRS calculations. In the mean over Ice-free ocean, CRS untuned SW calculations at TOA are closer to the Rev1 corrected observations, than they are to original SSF observations.

The CERES Science Team has approved a table of scaling factors known as Rev1. When a user orders a CRS file, an SSF file will come automatically attached; the file has SSF parameters first, then CRS parameters. The broadband SSF observations should be corrected as per CER_SSF_Terra_Edition2A.html.

This revision is necessary to account for spectral darkening of the transmissive optics on the CERES SW channels. By June 2005, this darkening has reduced the average global all-sky SW flux measurements by 1.1 and 1.8 percent for Terra FM1 and FM2 data respectively. A complete description of the physics of this darkening appears in the CERES BDS Quality Summaries under the Expected Reprocessing section. After application of this revision to the Edition2A CRS data set, users should refer to the data as Terra Edition2A-Rev1 CRS.

Cautions and Useful Hints

Informal additions to this document will be posted at the CAVE web site under "CRS Advice". This is the first release of a Terra CRS, and documentation is sparse. The Quality Summary of the earlier TRMM CRS Edition 2C is more extensive and may be a helpful guide at this stage. Neither document assesses the archived in-atmosphere fluxes at 500 hPa, 200 hPa (near the tropopause outside the tropics), and 70 hPa (near the tropical tropopause) with aircraft data. Experience with even the best regarded ground radiometer records has repeatedly pointed to the need for better characterization of validation data (Charlock and Alberta, 1996, Charlock et al., 2000); there indeed have been improvements (ie., Haefflelin et al., 2001). Both Terra and TRMM CRS results have too much absorption of SW within the atmosphere over regions with significant desert dust. Here are important differences of TRMM CRS Edition2C and Terra Edition2A:

1. The Langley Fu-Liou code for Terra is better. It includes an additional ~5 Wm^{-2} of absorption of SW in the atmosphere (HITRAN 2000 database); this influences the surface insolation. It more realistically accounts for the inhomogeneity of cloud optical depth with the Kato et al. (2004) application of the gamma distribution; this affects the reflection to TOA.
2. The AOT input for Terra is better. Over land, the improved AOT probably has more impact on surface insolation than do the code changes mentioned above. Terra has MODIS (MOD04) retrievals of aerosols over both sea and land, while TRMM had AOT retrievals from VIRS only over the ocean. In addition, the Filmore et al. (2004) MATCH used in Terra assimilates MODIS, while the MATCH used in TRMM assimilated AVHRR AOT over the ocean only.
3. We are not sure if the temperature and humidity in Terra (GEOS4.0) is an improvement over TRMM (ECMWF). Users should follow the evaluation of surface LW (LW Dn Sfc) on the Validation Plots and Statistics as they are posted on the CAVE web site. The Validation Plots and Statistics posted on CAVE look like Table 4 in this document. The temperature and humidity inputs have a large impact on SARB fluxes, including those at 70 hPa, 200 hPa, and 500 hPa.

Accuracy and Validation

Accuracy and validation discussions are found in the following sections of Nature of the CRS Product.

- Comparison of computed radiation with observations at TOA
- Comparison with Surface Observations

Numbered items of Cautions and Useful Hints address accuracy and validation.

References

- List of CERES CRS References

Expected Reprocessing

In the next few months Terra CRS Edition 2B is expected; using an improved parameterization for desert dust, daily variations in the vertical profiles of aerosols constituents in each grid box, and better observed broadband fluxes from SSF. In the longer term, yet more advanced versions of CRS are expected. A future run will use a "frozen" NWP analysis. There will be advances in the TOA fluxes. SSF will use new techniques to identify multilayer clouds. For an indefinite time, however, we anticipate continuing, significant uncertainties in CRS products for

- surface SW and atmospheric absorption of SW because of mixed phase clouds (land and sea), aerosol single scattering albedo (land and sea) and AOT (land);
- LW fluxes at the surface and at 500 hPa because of multiple layer clouds (land and sea).

Referencing Data in Journal Articles

The CERES Team has gone to considerable trouble to remove major errors and to verify the quality and accuracy of this data. **Please provide a reference to the following papers when you publish scientific results with the CERES Terra Edition2A CRS data:**

Wielicki, B. A., B. R. Barkstrom, E. F. Harrison, R. B. Lee, G. L. Smith, and J. E. Cooper, 1996: Clouds and the Earth's Radiant Energy System (CERES): An Earth Observing System Experiment. Bull. Amer. Meteor. Soc., 77, 853-868.

Charlock, T. P., F. G. Rose, D. A. Rutan, D. Fillmore, and W. Collins, 2004: Global Retrievals of the Surface and Atmosphere Radiation Budget. Proceedings of AMS 13th Conference on Satellite Meteorology and Oceanography, 20-24 September 2004, Norfolk, Virginia.

When Langley ASDC data are used in a publication, **we request the following acknowledgement be included:** "These data were obtained from the NASA Langley Research Center EOSDIS Distributed Active Archive Center."

The Langley ASDC requests two reprints of any published papers or reports which cite the use of data that we have distributed. This will help us determine the use of data that we distribute, which is helpful in optimizing product development. It also helps us to keep our product references current.

Feedback

For questions or comments on the CERES Quality Summary, contact the User and Data Services staff at the Atmospheric Science Data Center.

Informal contact to the SARB WG is accessible by selecting "The Group" at the CAVE web site.

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